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(54) [Title of the Invention] EXPOSURE APPARATUS, ITS MANUFACTURING AND EXPOSURE METHOD, AND DEVICE MANUFACTURING METHOD

(57) [Abstract]

[Problem] To enable continuous correction of image forming performance without vibration, or achieve an increase in the numerical aperture of a projection optical system and the correction of image forming performance.

[Solution] An exposure apparatus having an illumination optical system IL for illuminating a pattern provided on a reticle R and a projection optical system T for forming an image of the pattern on a photosensitive substrate, which performs exposures through a liquid LQ located at least part of an optical path between the projection optical system and the photosensitive substrate, wherein the exposure apparatus further comprising refractive index adjusting means for adjusting the refractive index of the liquid.

[Claims]

[Claim 1] An exposure apparatus having an illumination optical system for illuminating a pattern provided on a reticle and a projection optical system for forming an image of the pattern on a photosensitive substrate, and which performs exposures through a liquid located at least part of an optical path between the projection optical system and the photosensitive substrate, the exposure apparatus comprising:

refractive index adjusting means for adjusting the refractive index of the liquid.

[Claim 2] The exposure apparatus according to claim 1, wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance of the projection optical system.

[Claim 3] The exposure apparatus according to claim 2, further comprising

image forming performance measuring means for measuring the image forming performance of the projection optical system,

wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance.

[Claim 4] The exposure apparatus according to claim 1, further comprising

variable factor sensing means for sensing the state of the factor causing a fluctuation in the image forming

performance of the projection optical system,

wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the state of the factor.

[Claim 5] The exposure apparatus according to claim 4, wherein

the illumination optical system is configured to be able to change the illumination conditions for the reticle,

the variable factor sensing means senses the state of the illumination conditions, and

the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the change in the illumination conditions.

[Claim 6] The exposure apparatus according to claim 4, wherein the variable factor sensing means discriminates the kind of reticle, and

the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the kind of reticle.

[Claim 7] The exposure apparatus according to any one of claims 1 through 6, further comprising

a photosensitive substrate holder for holding the photosensitive substrate,

wherein the photosensitive substrate holder includes a side wall for filling the liquid in an optical path between the projection optical system and the

photosensitive substrate, and a supply/recovery unit for supplying the liquid to the photosensitive substrate holder and recovering the liquid from the photosensitive substrate holder.

[Claim 8] The exposure apparatus according to any one of claims 1 through 7, wherein the refractive index adjusting means includes an additive supply unit for supplying an additive for adjusting the refractive index of the liquid and an additive recovery unit for recovering the additive from the liquid.

[Claim 9] An exposure method, including a step of illuminating a reticle under predetermined illumination conditions and a step of transferring a pattern provided on the reticle to a photosensitive substrate using a projection optical system, in which light from the projection optical system is guided to the photosensitive substrate through a predetermined liquid, the method comprising:

a step of adjusting the refractive index of the liquid to correct the image forming performance of the projection optical system.

[Claim 10] A device manufacturing method, including illuminating a reticle under predetermined illumination conditions and a step of transferring a device pattern provided on the reticle to a photosensitive substrate using a projection optical system, in which light from the projection optical system is guided to the photosensitive

substrate through a predetermined liquid, wherein

when at least either the reticle or the illumination conditions is changed, the refractive index of the liquid is changed.

[Claim 11] A method for manufacturing an exposure apparatus provided with an illumination optical system for illuminating a pattern provided on a reticle and a projection optical system for forming an image of the pattern on a photosensitive substrate, and provided for performing exposures through a liquid located at least part of an optical path between the projection optical system and the photosensitive substrate, the method comprising:

a step of measuring the image forming performance of the projection optical system, and

a step of determining an initial value for the refractive index of the liquid based on the measured image forming performance.

[Detailed Description of the Invention]

[0001]

[Field of the Invention] The present invention relates to an exposure apparatus equipped with a projection optical system for projecting a device pattern provided on a reticle to the surface of a photosensitive substrate, an exposure method using the exposure apparatus and device manufacturing method. More particularly, the present invention relates to an immersion exposure apparatus in which the optical path between the projection optical

system and a photosensitive substrate is filled with a liquid. The present invention is suitably used for manufacturing semiconductor devices, image pickup devices (such as CCDs), liquid crystal display devices, thin film magnetic heads, or the like.

[0002]

[Prior Art] A space between the last or front face of an optical system and an image surface is called working distance. The working distance of a projection optical system in the conventional exposure apparatus is filled with air. With ever increasing demand for finer patterns to be exposed to a silicon wafer in the process of manufacturing ICs or LSIs, it is necessary to make the exposure wavelength shorter or increase the numerical aperture on the image side. The shorter the light wavelength, the less the glass materials having satisfactory image forming performance and transmittance enough to ensure a satisfactory amount of exposure light.

[0003] Therefore, use of a liquid having a refractive index larger than that of air as the last medium to the image plane to increase the numerical aperture on the image side has been proposed. An exposure apparatus having a projection optical system using such a liquid is called an immersion exposure apparatus. On the other hand, there is known an exposure apparatus technique for providing an exchangeable image forming performance-correcting element in an optical path of the projection optical system closest

to the object side or the image side to adjust image forming performance in order to correct the image forming performance of the projection optical system.

[0004]

[Problems to be Solved by the Invention] However, since the immersion exposure apparatus is configured to fill a liquid in the optical path (working distance) between the projection optical system and the photosensitive substrate, it is difficult to arrange such an element to correct image forming performance. Further, since only a finite number of image forming performance-correcting elements, about a few pieces in consideration of practical exposure apparatus design, can be prepared, there also arises a problem that can correct image forming performance only in a discrete manner.

[0005] The image forming performance of the projection optical system also needs to fall within a predetermined allowable range, but the discrete correction of the image forming performance makes it difficult for the image forming performance to fall within the predetermined allowable range. Especially, as the exposure pattern is required to be finer or the exposed area is required to be larger, the allowable range of the image forming performance is narrowed. Even using such a scanning exposure method to perform exposures while scanning the reticle and the photosensitive substrate, since the allowable range of changes in image forming performance

characteristics is narrowed, the discrete correction is insufficient.

[0006] In addition, during replacement of image forming performance-correcting elements, vibration occurs in the projection optical system itself, and this could adversely affect the image forming performance. Therefore, it is a first object of the present invention to enable continuous correction of image forming performance without vibration. It is a second object of the present invention to achieve an increase in the numerical aperture of a projection optical system and the correction of image forming performance.

[0007]

[Means for Solving the Problems] In order to attain the first object of the present invention, there is provided an exposure apparatus having an illumination optical system for illuminating a pattern provided on a reticle and a projection optical system for forming an image of the pattern on a photosensitive substrate, and which performs exposures through a liquid located at least part of an optical path between the projection optical system and the photosensitive substrate, the exposure apparatus comprising refractive index adjusting means for adjusting the refractive index of the liquid.

[0008] According to a preferred embodiment as set forth in claim 2, the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming

performance of the projection optical system. According to another preferred embodiment as set forth in claim 3 based on the above structure, the exposure apparatus further comprises image forming performance measuring means for measuring the image forming performance of the projection optical system, wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance.

[0009] According to still another preferred embodiment as set forth in claim 4, the exposure apparatus further comprises variable factor sensing means for sensing the state of the factor causing a fluctuation in the image forming performance of the projection optical system, wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the state of the factor. According to yet another preferred embodiment as set forth in claim 5 based on the above structure, the illumination optical system is configured to be able to change the illumination conditions for the reticle, the variable factor sensing means senses the status of the illumination conditions, and the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the change in the illumination conditions.

[0010] According to yet another preferred embodiment as set forth in claim 6, the variable factor sensing means

discriminates the kind of reticle, and the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the kind of reticle. Further, in order to attain the above-mentioned second object, it is preferable that the liquid be filled in the entire range of the optical path between the projection optical system and the photosensitive substrate. In this case, it is preferably that the exposure apparatus according to the present invention should include a side wall for filling the liquid in the optical path between the projection optical system and the photosensitive substrate and a supply/recovery unit for supplying the liquid to the photosensitive substrate holder and recovering the liquid from the photosensitive substrate holder, and further include a photosensitive substrate holder for holding the photosensitive substrate.

[0011] It is also preferable that the refractive index adjusting means should include an additive supply unit for supplying an additive for adjusting the refractive index of the liquid and an additive recovery unit for recovering the additive from the liquid.

[0012]

[Embodiments of the Invention] In the structures of the present invention as mentioned above, since the refractive index of the liquid located in the optical path between the projection optical system and the photosensitive substrate can be adjusted, the image forming performance of the

projection optical system can be corrected according to the change in the refractive index. In a refractive index adjusting technique, if the liquid is a mixed liquid of multiple substances, the refractive index n of the mixed liquid is determined according to the Lorentz-Lorenz formula:

[0013]

[Eq. 1]

$$\left(\frac{n^2-1}{n^2+2}\right) = \sum_{i=1,2,\ldots} m_{(i)} \times \left(\frac{n_{(i)}^{\ 2}-1}{n_{(i)}^{\ 2}+2}\right) \times \frac{\rho}{\rho_{(i)}}$$

[0014] In this equation,

[0015]

[Eq. 2]

$n_{(i)}$ is the refractive index of the i-th substance,

$m_{(i)}$ is the weight fraction of the i-th substance, and

$\rho_{(i)}$ is the concentration of the i-th substance.

[0016] For example, if the liquid is an aqueous solution, the refractive index of the aqueous solution varies according to the concentration of the aqueous solution itself. Therefore, the concentration of the substances added to the aqueous solution can be increased or decreased. Thus, the refractive index of the liquid can be changed to have a refractive index value enough to compensate the image forming performance of the projection optical system in order to optimize the image forming performance of the projection optical system.

[0017] The adjustment of refractive index can be made, for example, by measuring image forming performance such as aberration of the projection optical system to adjust the refractive index according to the measurement result. Alternatively, a fluctuation in a factor corresponding to a fluctuation in the image forming performance of the projection optical system can be sensed to adjust the refractive index according to the sensing result. In the former technique for measuring the image forming performance of the projection optical system, aberration or the like of the projection optical system can be measured during manufacturing of the exposure apparatus to set a refractive index value enough to compensate for the aberration as an initial value for the refractive index of the liquid. The adjustment of the refractive index in part of the adjustment process during manufacturing has the advantage of making adjustment and manufacturing work easy. In addition, an aberration measuring mechanism can also be provided in the exposure apparatus itself to change the refractive index of the liquid according to the result of aberration measurement by the aberration measuring mechanism.

[0018] On the other hand, in the latter technique, the kind of reticle, the status of illumination conditions, the amount of energy passing through the projection optical system or the like is considered to be the factor in which a fluctuation corresponding to the fluctuation in image

forming performance occurs. Here, since the illumination conditions (σ value, whether it is distorted illumination or not, etc.) for illuminating a reticle are optimized depending on the kind of pattern provided on the reticle, the image forming performance of the projection optical system including its aberration is changed when the illumination conditions are changed. A refractive index value for compensating the image forming performance varying with a fluctuation in each factor such as the kind of reticle or each of the illumination conditions is prestored in a memory or the like on a factor basis, so that a fluctuation in the factor can be sensed to adjust the refractive index of the liquid based on the stored relation. The image forming performance of the projection optical system also varies as the amount of exposure energy passing through the projection optical system increases or decreases, called projection fluctuation. In this case, the amount of exposure energy and a refractive index value for compensating the image forming performance varying with an increase or decrease in the amount of exposure energy are also prestored in a memory or the like, so that a fluctuation in this factor can be sensed to adjust the refractive index of the liquid based on the stored relation. In this technique, the refractive index value may be calculated according to a predetermined formula instead of being prestored in a memory.

[0019] The adjustment of the refractive index of the liquid

is effective in correcting the image forming performance of the projection optical system, especially spherical aberration or image surface curvature. The following describes preferred embodiments of the present invention with reference to the drawings.

[First Embodiment] FIG. 1 is a schematic diagram showing an exposure apparatus according to a first embodiment of the present invention. In FIG. 1, an XYZ coordinate is employed.

[0020] In FIG. 1, a light source S supplies exposure light having a wavelength of 248nm. The exposure light from the light source S illuminates the reticle R through an illumination optical system IL and a reflecting mirror M with a substantially uniform luminance distribution. In the embodiment, a KrF excimer-laser light source is used as the light source S, but any other type of light source may be used, such as an ArF excimer-laser light source supplying exposure light having a wavelength of 193nm or a high-pressure mercury lamp supplying g- or i-line light. Though not shown in FIG. 1, the illumination optical system IL has an optical integrator for forming a surface light source, a condenser optical system for condensing light from the surface light source to illuminate a projected surface uniformly in a superimposed manner, and a variable aperture stop arranged in the position of the surface light source formed by the optical integrator so that it will vary the shape of the surface light source. As the shape of the surface light source, a shape having a plurality of surface

light sources eccentric from the optical axis, the shape of an annular zone, various circular shapes of different sizes, etc, are used. As the illumination optical system IL, an illumination optical system disclosed, for example, in US Patent No. 5,329,094 or US Patent No. 5,576,801 can be used.

[0021] The exposure light that passed through the reticle R and was diffracted reaches the surface of the wafer W through a projection optical system T and forms an image of the reticle R on the wafer. The reticle R is held by a reticle loader RL. The reticle loader RL is capable of being driven by a drive unit T1 to move on a loader table LT along the X and Y axes at any speed at any time as required. The moving speed of the reticle loader RL on the loader table LT is sensed by a speed sensor SS, and the output of the speed sensor SS is sent to a first control part CPU 1.

[0022] The wafer W is held by a wafer table WT. The wafer table WT is provided with a side wall for pooling the liquid LQ. In the embodiment, the side wall allows the entire optical path from the wafer W to the projection optical system T to be filled with the liquid LQ. The wafer table WT is capable of being driven by a drive unit T2 to move on a holder table HT at any speed in the directions along the X and Y axes.

[0023] The first control part CPU 1 calculates the moving speed of the wafer table WT on the holder table from the moving speed of the reticle loader RL on the loader table

LT and the exposure magnification β of the projection optical system T to send the calculated moving speed to the drive unit T2. The drive unit moves the wafer table WT based on the moving speed sent from the first control part CPU 1.

[0024] FIG. 2 is a view showing a detailed configuration of the wafer table WT. In FIG. 2, the optical part closet to the wafer W side in the projection optical system T and a metal frame of the projection optical system T are brought into tight contact with each other without any clearance, or packing is inserted in the clearance. A plurality of openings are also provided in the bottom portion of the wafer table WT to draw the wafer W by suction on the wafer table WT by decreasing the pressure from piping V connected to these openings. Further, electrodes D1, D2 are provided in the wafer table WT, and ion exchange membranes I1, I2 are provided around these electrodes D1, D2, respectively. These ion exchange membranes I1, I2 separate the region around each of the electrodes D1, D2 from a region in which the exposure light passes through the liquid LQ. The atmosphere around the electrode D1 is an enclosed space by means of the ion exchange membrane I1 and a dividing wall K1, and an exhaust pipe H1 is connected to the enclosed space. The atmosphere around the electrode D2 is also an enclosed space by means of the ion exchange membrane I2 and a dividing wall K2, and an exhaust pipe H2 is connected to the enclosed space. These exhaust pipes H1, H2 are

connected to a mixing unit K. One end of an inlet tube LD equipped with an electromagnetic valve DV is connected to the mixing unit K, and the other end of the inlet tube LD is located near the wafer table WT.

[0025] Applied voltage to the electrodes D1, D2 is supplied from a power supply unit, not shown, and the applied voltage supplied from the power supply unit is controlled by a second control part CPU 2. The opening and closing of the electromagnetic valve DV is also controlled by the second control part CPU 2. In the embodiment, the electrodes D1, D2, the ion exchange membranes I1, I2, the dividing walls K1, K2, the exhaust pipes H1, H2, the mixing unit K, the electromagnetic valve DV, the inlet tube LD, the power supply unit, not shown, and the second control part CPU 2 constitute refractive index adjusting means.

[0026] The following describes the operation of the refractive index adjusting means. In the following description, the liquid LQ is pure water with hydrogen chloride added in it as an additive. First, when the refractive index of the liquid LQ should be reduced, the second control part CPU 2 sends an instruction to the power supply unit to apply a predetermined voltage between the electrode D1 and the electrode D2 for a predetermined period of time. During this period, oxygen gas is generated from the electrode on the anode side and a gas mixture of hydrogen and chlorine is generated from the electrode on the cathode side. Since the concentration of hydrogen

chloride in the liquid LQ is reduced, the refractive index of the liquid LQ is also reduced as apparent from the above equation (1). The gases respectively generated near the electrodes D1, D2 do not pass through the ion exchange membranes I1, I2, so that they can be recovered through the exhaust pipes H1, H2. The recovered gases are sent to the mixing unit K. In the mixing unit K, the recovered gases (oxygen gas, hydrogen gas, and hydrochloric gas) are mixed to generate an additive aqueous solution with a solute concentration higher than the liquid LQ.

[0027] On the other hand, when the refractive index of the liquid LQ is increased, the second control part CPU 2 sends an instruction to the electromagnetic valve DV to open so that the high-concentration additive aqueous solution will be added to the liquid LQ to increase the refractive index of the liquid LQ. This structure makes it possible to vary the refractive index of the liquid LQ. A refractive index value for each of various illumination conditions is stored in the form of a table in a memory M1 connected to the second control part CPU 2. The refractive index value is the refractive index of the liquid LQ required to correct aberration caused in the projection optical system T under a corresponding illumination condition. In the memory M1, an additive concentration value in the liquid LQ at a certain point of time is held and updated.

[0028] The illumination optical system IL is connected to the second control part CPU 2 to send the second control

part CPU 2 information relating to the shape of the surface light source formed by the illumination optical system IL. when an illumination condition, that is, the shape of the surface light source in this embodiment, is changed, this information is sent to the second control part CPU 2. The second control part CPU 2 retrieves a refractive index value corresponding to the sent illumination condition from the memory M1, and calculates an additive concentration according to the above equation (1) to achieve the refractive index. Then, based on the current additive concentration stored in the memory M1 and the calculated additive concentration, the second control part CPU 2 controls the electrodes D1, D2 or the electromagnetic valve DV to change the current additive concentration to the calculated additive concentration.

[0029] Thus, the refractive index of the liquid LQ is adjusted to correct the aberration of the projection optical system T including the liquid LQ.

[Second Embodiment] A major point in a second embodiment that differs from the first embodiment is that the second embodiment uses ethyl alcohol as the additive. Ethyl alcohol has the advantages of not dissolving the resist layer of the wafer W coated with a resist to form a photosensitive substrate, and less influence on the optical part closest to the wafer W side in the projection optical system T (that is, the optical part contacting the liquid LQ) and the optical coating on the optical part.

[0030] In addition, the structure of the refractive index adjusting means in the second embodiment is different from that in the first embodiment. Referring to FIG. 3, the structure of the refractive index adjusting means will be described below. Note that in FIG. 3 parts or members having the same functions as those in FIG. 2 are given the same reference numerals and symbols. In FIG. 3 showing the wafer table WT according to the second embodiment, points different from the first embodiment are that an additive supply pipe LS for supplying an additive to the liquid LQ, a pure water supply pipe WS for supplying pure water to the liquid LQ, and an exhaust pipe L for discharging the liquid LQ to prevent an overflow of the liquid LQ from the wafer table WT are provided.

[0031] Electromagnetic valves DVLS, DVWS are provided in the additive supply pipe LS and the pure water supply pipe WS, respectively, to adjust the supply of the additive and the pure water, and an electromagnetic valve DVL is provided in the exhaust pipe L to adjust the amount of discharge of the liquid LQ. The opening and closing of these electromagnetic valves DVLS, DVWS, DVL is controlled by the second control part CPU 2. The following describes the operation of adjusting the refractive index in the second embodiment.

[0032] First, when the refractive index of the liquid LQ is increased, the second control part CPU 2 controls the electromagnetic valve DVLS to add a prescribed amount of

additive to the liquid LQ. At this time, the liquid LQ is discharged by a prescribed amount through the exhaust pipe L. It is preferable that the amount of discharge of the liquid LQ be equal to the amount of additive added to the liquid LQ. This increases the additive concentration in the liquid LQ and hence the refractive index.

[0033] On the other hand, when the refractive index of the liquid LQ is reduced, the second control part CPU 2 controls the electromagnetic valve DVWS to add a prescribed amount of pure water to the liquid LQ. At this time, the liquid LQ is discharged by a prescribed amount through the exhaust pipe L. It is preferable that the amount of discharge of the liquid LQ be equal to the amount of pure water added to the liquid LQ. This reduces the additive concentration in the liquid LQ and hence the refractive index.

[0034] The amounts of added additive and pure water, and the amount of discharge of the liquid LQ are controlled by the second control part CPU 2. The other points that a refractive index value for each of various illumination conditions is stored in the memory M1, an additive concentration value in the liquid LQ at a certain point of time is held, and an additive concentration is calculated based on these pieces of information to achieve a refractive index that can correct the aberration of the projection optical system T are the same as in the first embodiment.

[0035] Then, based on the current additive concentration stored in the memory M1 and the calculated additive concentration, the second control part CPU 2 in the second embodiment controls the opening and closing of the electromagnetic valves DVLS, DVWS, DVL to change the current additive concentration to the calculated additive concentration. Thus, the refractive index value of the liquid LQ is adjusted to correct the aberration of the projection optical system T including the liquid LQ.

[Third Embodiment] Referring next to FIG. 4, a third embodiment will be described. An exposure apparatus according to the third embodiment is different from the first and second embodiments in that it is provided with an aberration measuring device. Note that in FIG. 4 parts or members having the same functions as those in FIGS. 1 to 3 are given the same reference numerals and symbols, and the same XYZ coordinate system as in FIG. 1 is employed.

[0036] In FIG. 4, the light source S supplies exposure light having a wavelength of 248nm. The exposure light from the light source S is shaped by a beam shaping optical system 11 into a predetermined cross section, and is incident on a first fly-eye lens 12. Secondary light sources consisting of a plurality of light source images are formed on the exit side of the first fly-eye lens 12. The exposure light from the secondary light sources is incident on a second fly-eye lens 15 through a relay lens system 13F, 13R. This relay lens system includes a front

group 13F and a rear group 13R, and a vibration mirror 14 is arranged between the front and rear groups to prevent the occurrence of speckles on the projected surface.

[0037] Images of the plurality of secondary light sources formed through the first fly-eye lens are formed as tertiary light sources on the exit surface side of the second fly-eye lens 15. A variable aperture stop 16 capable of setting a plurality of aperture stops having predetermined shapes or sizes is arranged at a position in which the tertiary light sources are formed. For example, as shown in FIG. 5, the variable aperture stop 16 has six aperture stops 16a-16e patterned in the form of a turret on a transparent substrate made of quartz and the like. Among these aperture stops, two aperture stops 16a, 16b each having a circular opening are to change the σ value (the numerical aperture of the illumination optical system relative to the numerical aperture of the projection optical system), and two aperture stops 16c, 16d each having the shape of an annular zone are different in the proportion of annular zones. The remaining two aperture stops 16e, 16f have four eccentric openings, respectively. The variable aperture stop 16 is driven by a variable aperture stop driving unit 17 to locate any one of the plurality of aperture stops 16a-16f in the optical path.

[0038] Returning to FIG. 4, the exposure light from the variable aperture stop 16 is condensed by a condenser lens system 18 to illuminate a reticle blind 19 in a

superimposed manner. The reticle blind 19 is conjugated with a pattern formed surface of the reticle R with respect to a relay optical system 20F, 20R so that the shape of the illuminated area on the reticle R will be defined depending on the shape of the opening of the reticle blind 19. The exposure light from the reticle blind 19 forms an illuminated area in a predetermined position on the reticle with a substantially uniform luminance distribution through the front-group relay optical system 20F, a reflecting mirror M, and the rear-group relay optical system 20R.

[0039] Note that the illumination optical system IL in the above first and second embodiments can also be replaced with the structure from the beam shaping optical system 11 to the relay optical system 20F, 20R in this embodiment. The reticle R is loaded on a reticle loader RL. The reticle loader RL can move on the holder table LT not only in the X and Y directions but in the direction of rotation about the Z axis (θ direction) as shown in the figure. A moving mirror RIM is provided in the reticle loader RL, and a reticle interferometer RI detects the position of the reticle loader RL in the XY and θ directions. The reticle loader RL is driven by a reticle loader driving unit RLD in the XY and θ directions. The output of the reticle interferometer RI is sent to the first control part CPU 1 so that the first control part CPU 1 will control the reticle loader driving unit RLD.

[0040] A barcode reader BR for reading a barcode provided

on a reticle R is provided at some midpoint in a transport track from a reticle stocker, not shown. Information on the kind of reticle R obtained from the barcode read by the barcode reader BR is sent to the second control part CPU 2. Here, information relating to the optimum illumination condition for each kind of reticle R and the optimum refractive index value of the liquid LQ for each kind of reticle R are stored in the memory M1 connected to the second control part CPU 2.

[0041] The projection optical system T having a predetermined reduction ratio $|\beta|$ is provided underneath the reticle R, and the liquid LQ lies between the optical part closest to the wafer surface side in the projection optical system T and the wafer W. the projection optical system T forms a reduced image of the reticle R on the wafer surface through the liquid LQ. The wafer W is fixed by suction on the wafer table WT. The wafer table WT is mounted on a wafer stage WTS through Z actuators ZD1, ZD2, ZD3 for actuating the wafer table WT to move in the Z direction or tilt (with respect to the Z axis). The wafer stage WTS is movable in the XY directions with respect to a base. The wafer stage WTS is driven by a wafer stage driving unit WD. The side wall of the wafer table is mirror-finished, and this mirror-finished portion serves as a moving mirror for a wafer interferometer WI. The wafer stage driving unit WD is controlled by the first control part CPU 1, and the output of the wafer interferometer WI is sent to the first

control part CPU 1.

[0042] A focus sensor AF is provided in the projection optical system T to measure the distance in the Z direction between the projection optical system T and the wafer W. The focus sensor AF projects a beam to the wafer surface through the optical element closest to the wafer W side in the projection optical system T, and receives a reflected beam from the wafer through the optical element to measure the distance in the Z direction between the projection optical system T and the wafer W based on the beam receiving position. The structure of such a focus sensor AF is disclosed, for example, in Japanese Patent Laid-Open No. 06-66543.

[0043] The additive supply pipe LS for supplying to the liquid LQ a high-concentration additive aqueous solution stored in an additive storage unit LST, and the pure water supply pipe WS for supplying to the liquid LQ pure water stored in a pure water storage unit WST are also provided in the third embodiment. Likewise, the electromagnetic valves DVLS, DVWS are provided in the additive supply pipe LS and the pure water supply pipe WS, respectively, to adjust the amounts of supply of the additive aqueous solution and the pure water, respectively. Further, the exhaust pipe L is provided in the wafer table WT to discharge the liquid LQ in order to prevent an overflow of the liquid LQ from the wafer table. The electromagnetic valve is also provided in the exhaust pipe L to adjust the

amount of discharge of the liquid LQ. The opening and closing of these electromagnetic valves DVLS, DVWS, DVL is controlled by the second control part CPU 2 in the same manner as in the above second embodiment.

[0044] In addition, an aberration measuring part AS for measuring the aberration of the projection optical system and an additive concentration detecting part DS for detecting the additive concentration of the liquid LQ are provided on the wafer table WT. A component disclosed, for example, in Japanese Patent Laid-Open No. 06-84757 can be used as the aberration measuring part. The output of the aberration measuring part AS and the additive concentration detecting part DS is sent to the second control part CPU 2. The output of the additive concentration detecting part DS is stored in the memory M1 through the second control part CPU 2 as an additive concentration value of the liquid LQ at a certain point of time.

[0045] The following describes the operation of the third embodiment. First, the barcode reader BR reads the barcode provided on the reticle R at some midpoint between when the reticle R was pulled out of the reticle stocker, not shown, and when it is loaded on the reticle loader RL, and sends the information to the second control part CPU 2. The second control part CPU 2 then reads the information relating to the illumination condition corresponding to the kind of reticle R stored in the memory M1, and controls the variable aperture stop driving unit 17 based on the

information to locate a corresponding one of the aperture stops 16a-16f in the optical path. Then, based on the refractive index value of the liquid LQ stored in the memory M1, the second control part CPU 2 calculates an additive concentration required to achieve the refractive index according to the above equation (1). After that, based on the current additive concentration detected by the additive concentration detecting part DS and stored in the memory M1 and the calculated additive concentration, the second control part CPU 2 controls the opening and closing of the electromagnetic valves DVLS, DVWS, DVL to change the current additive concentration to the calculated additive concentration.

[0046] Thus, the refractive index value of the liquid LQ is adjusted to correct the aberration of the projection optical system T including the liquid LQ. After that, the focus sensor AF detects the position and tilt of the wafer W in the Z direction to drive the Z actuators ZD1, ZD2, ZD3 in order to move the wafer W to a required position. Under this condition, the exposure light from the light source S is guided to the reticle R through the illumination optical system. The first control part CPU 1 controls the reticle interferometer RI and the wafer interferometer WI to detect the position of the reticle R and the wafer W, while it actuates the reticle loader driving unit RLD and the wafer stage driving unit WD to move the reticle R and the wafer W with a speed ratio corresponding to the reduction ratio $|\beta|$.

This makes it possible to transfer the pattern on the reticle R to the surface of the wafer W under good imaging conditions.

[0047] The image forming performance (such as aberration) of the projection optical system T does not always constant, that is, it could vary with a temperature change, an atmospheric pressure change, or a temperature rise caused by the projection optical system T absorbing the exposure light. Therefore, in the third embodiment, the aberration measuring part AS measures the actual aberration (image forming performance) of the projection optical system T to adjust the refractive index of the liquid LQ based on the measurement result.

[0048] Specifically, in the third embodiment, a refractive index value of the liquid LQ enough to correct the aberration is stored in the memory M1 in association with the aberration value of the projection optical system. The aberration of the projection optical system T detected by the aberration measuring part AS is sent to the second control part CPU 2. The second control part CPU 2 reads the refractive index value of the liquid LQ stored in the memory M1, calculates an additive concentration to achieve the refractive index value according to the above equation (1), and controls the opening and closing of the electromagnetic valves DVLS, DVWS, DVL to change the current additive concentration of the liquid LQ to the calculated additive concentration.

[0049] This structure makes it possible to keep the image forming performance in good condition even if an environmental change (temperature change, atmospheric pressure change, or fluctuation caused by absorption of exposure light) occurs in the projection optical system T. Note that the aberration measuring part AS does not need to perform measurements at all times, that is, it has only to perform measurements at every predetermined interval.
[Fourth Embodiment] Referring next to FIG. 6, a fourth embodiment will be described. An exposure apparatus according to the fourth embodiment is configured to fill the liquid in part of the optical path between the projection optical system and the wafer, rather than in the entire optical path.
[0050] In FIGS. 6(a), (b), parts or members having the same functions as those in the first and second embodiments shown in FIGS. 1-3 are given the same reference numerals and symbols. In the fourth embodiment shown in FIGS. 6(a), (b), a point different from the first and second embodiments is that the liquid LQ is filled in cases C1, C2 made of a material (such as quartz) capable of allowing the exposure light to pass through, instead of pooling the liquid LQ by means of the side wall of the wafer holder WT. Among the advantages of the first and second embodiments, the structure of this embodiment does not have the advantages of increasing the numerical aperture and the effective depth of focus, but it has the advantage of being

able to continuously adjust the aberration (image forming performance) of the projection optical system T.

[0051] In the fourth embodiment, the cases C1, C2 containing the liquid LQ may be provided integrally with the projection optical system T. In the aforementioned first-fourth embodiments, pure water is used as the liquid LQ, but the liquid LQ is not limited to the pure water.

[0052]

[Effects of the Invention] As described above, according to the present invention, the image forming performance of the projection optical system can be adjusted continuously without vibration. It is also possible to achieve an increase in numerical aperture (or an increase in the effective depth of focus) and the adjustment of image forming performance.

[Brief Description of the Drawings]

[FIG. 1] It is a schematic diagram showing the overall structure of an exposure apparatus according to first and second embodiments of the present invention.

[FIG. 2] It is a sectional view showing the main part of the exposure apparatus according to the first embodiment of the present invention.

[FIG. 3] It is a sectional view showing the main part of the exposure apparatus according to the second embodiment of the present invention.

[FIG. 4] It is a schematic diagram showing an exposure apparatus according to a third embodiment of the present

invention.

[FIG. 5] It is a schematic view showing part of the exposure apparatus according to the third embodiment of the present invention.

[FIG. 6] It is a sectional view showing the main part of the exposure apparatus according to the third embodiment of the present invention.

[Description of Notations]

S … Light Source T2 … Drive Unit

IL … Illumination Optical System M1 … Memory

M … Reflecting Plate V … Decompression Pipe

T … Projection Optical System D1, D2 … Electrodes

W … Wafer I1, I2 …Ion Exchange Membrane

LQ … Liquid K1, K2 … Dividing Wall

R … Reticle H1, H2 …Piping

RL … Reticle Loader L …Exhaust Pipe

LT … Loader table LD …Inlet Tube

SS … Sensor WS … Pure Water Supply Pipe

WT … Wafer Table LS …Additive Supply Pipe

T1 … Drive Unit